INNOVARE JOURNAL OF AGRICULTURAL SCIENCE

Vol 1, Issue 2 , 2013 ISSN 2321-6832

Research Article

EFFECT OF MOISTURE CONTENT ON SOME PHYSICAL, MECHANICAL PROPERTIES OF LIMA BEAN (*PHASEOLUS LUNATUS*), AN UNDERUTILIZED COMMON FOOD LEGUME

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Received: 27 September 2013, Revised and Accepted:8 October 2013

ABSTRACT

The physical and mechanical properties of lima bean seeds were determined as a function of moisture content in the range of 11.02 ± 0.05 to 24.15± 0.12 % (d.b). The length, width and breadth of the lima bean seeds increased from 15.32 ± 0.72 to16.16 ± 0.31 mm, 7.92 ± 0.27 to 9.02 ± 0.10 mm, 4.94 ± 0.24 to 5.68 ± 0.26 mm, respectively, with increase in moisture content from 11.02 ± 0.05 to 24.15± 0.12 % (d.b). One thousand seed weight increased linearly from 423 ± 0.24 to 532 ± 0.32 g. The bulk density decreased from 0.662 ± 0.03 to 0.583 ± 0.13 gcm-3, while the true density increased from 0.918 ± 0.03 to 1.153 ± 0.13 gcm-3 in the moisture content range. The porosity and sphericity values of lima bean seed increased linearly from 27.88 ± 0.05 to 49.43 ± 1.12, 0.548 ± 0.01 to 0.579 ± 0.09 %. The maximum static coefficients of friction were noticed on rubber surface, followed by stainless steel, plywood, galvanized iron, aluminium and glass surfaces. The results are necessary for design of equipment to handling, transportation, processing, and the storage of lima bean seed.

Keywords: Lima bean, physical and mechanical properties, moisture content, coefficient of friction, thousand seed mass.

INTRODUCTION

Lima bean (Phaseolus lunatus) is a warm season vegetable of the legume family and is closely related to green beans, kidney beans, and wax beans. Lima bean is one of the most widely cultivated pulse crops both in temperate and subtropical regions. It is adapted to highly leach infertile soils of the more humid regions. In recent time plant geneticists have improved the lima bean enormously and a number of early maturing, disease and pest resistant, non-toxic cultivars are widely available commercially[1]. Lima bean has desirable agronomic and nutritional characteristics[2]. According to[3, 4,] it is widely available and thrives in lowland tropical rain forest areas and on poor soils where most crops cannot grow well. Lima bean has crude protein content of about 22% and yields between 3000kg and 5000kg of seeds per hectare[3]. Lima bean is rich in niacin, thiamine and riboflavin5. They are said to contain high levels of potassium, phosphorus, calcium and iron[6, 7]. However, like other tropical legumes, lima bean seed contains some anti-nutritional factors, which limit its utilization in animal feeding. These include phytins and tannins[8, 4] hydrogen cyanide and trypsin inhibitors[9]. Lima bean is cultivated primarily for its immature and dry seeds, which in tropical Africa are usually eaten boiled, fried in oil or baked. In Nigeria they are also cooked with maize, rice or yam and used in making special kinds of soup and stew. The Yoruba people process the seeds into porridges, puddings and cakes. Immature green seeds, young pods and leaves are eaten as a vegetable, e.g. in Ghana and Malawi. In the United States, fresh and dry Lima beans are processed on an industrial scale involving canning and freezing. Sprouts and young plants are cooked and eaten in many Asian countries. In order to design equipment for the handling, conveying, separation, drying, aeration, storing and processing of lima bean seeds, it is necessary to determine their physical and mechanical properties as a function of moisture content. The knowledge of lima bean seed such as dimensions of the seed, porosity, density, coefficient of static friction, etc. is necessary to design of lima bean seed processing equipment. For instance, dimensions and porosity of the seed are the most important for packing. The density of the seed is significant in numerous technological processes and in the evaluation of product quality. The coefficient of static friction play important role in transports of goods and storages facilities.

The purpose of this study was to investigate the effect of moisture content on the physical and mechanical properties of the lima bean seeds such as axial dimension, geometric and arithmetic mean diameter, sphericity, surface area, unit mass, thousand grain mass, true volume, true and bulk densities, porosity, static coefficient of friction of lima bean seeds.

MATERIALS AND METHODS

Sample collection

The Lima bean (Phaseolus lunatus) used in the study was obtained from a local market (Madurai, Tamilnadu, India). The legumes were cleaned manually to remove all foreign matter such as dust, dirt, stones and chaff as well as immature, broken grains. Lima bean seeds were used to determine the physical and mechanical properties.

Moisture content determination

The samples of each one 1500 grains of the 11.02, 14.24, 16.23, 19.14 and 24.15% (d.b) moisture contents were prepared by adding the amount of distilled water calculated[10,11] using the following equation:

$$Q = \frac{W_i(M_f - M_i)}{100 - M_f} \quad (1)$$

Where, W_i = initial mass of sample, M_i = initial moisture content of sample, % (d.b). M_f = final moisture content of sample, % (d.b).

The samples were then placed inside polyethylene bags and sealed tightly. The samples were kept at 5°C in a common refrigerator for a week to enable the moisture to distribute uniformly throughout the sample. Before starting a test, 1000 grains from each one polyethylene bags was taken out of the refrigerator and allowed to equilibrate to the room temperature for about 2 h[12]. All the physical properties of the grains were determined at five moisture content levels ranging from 11.02 to 24.15% (d.b.) with ten replications at each moisture content level. These values are within the range of moisture contents for lima bean grains recommended for safe module storage as 12.35 % (d.b.) on 5°C[13].

Physical properties of Lima bean seeds

The geometrical dimensions namely length x, width y and breadth z from Jack bean seeds were measured with a digital Verrnier calliper (Mitutoyo, Japan) with an accuracy of ± 0.01mm. The arithmetic mean diameter, D_a and geometric mean diameter, D_g of seed and kernels were calculated from the geometrical dimensions as[14, 15]:

$D_a = \frac{(X+Y+Z)}{3}$ (2)

$D_g = (x.y.z)^{1/3}$ (3)

Sphericity was calculated based on the isoperimetric property of a sphere.

$\Phi = \frac{Dg}{X}$ (4)

The square mean diameters (SMD), equivalent diameter (EQD) were determined by the method of[16]. The aspect ratio was evaluated by[17, 18].

Surface area

The surface area A_s in mm^2 of the grains was found by analogy with a sphere of same geometric mean diameter, using the following relationship[19].

$A_s = S = \pi Dg^2$ (5)

Where D_g geometric mean diameter (mm).

Bulk density

The average bulk density of the grain was determined using the standard test weight procedure[20] by filling a container of 500 ml with the grain from a height of 150 mm at a constant rate and then weighing the content.

True density

The average true density was determined using the toluene displacement method. The volume of toluene (C_7H_8) displaced was found by immersing 50 g of white kidney bean grains in the toluene[11]. The porosity (ε) of bulk seed was computed from the values of true density (ρ_t) and bulk density (ρ_b) using the relationship[21]:

$\varepsilon = 1 - \left(\frac{\rho_b}{\rho_t}\right) * 100$ (6)

Static coefficient of friction

The static coefficient of friction of lima bean seeds against six different structural materials, namely rubber, plywood, stainless steel, aluminium, galvanized iron and glass was determined. A glass box of 150mm length, 100 mm width and 40 mm height without base and lid was filled with sample and placed on an adjustable tilting plate, faced with test surface.

The sample container was raised slightly (5 to10 mm) so as not to touch the surface. The inclination of the test surface was increased gradually with a screw device until the box just started to slide down and the angle of tilt was measured from a graduated scale. For each replicate, the sample in the container was emptied and refill with a new sample[22]. The static coefficient of friction was calculated based on this equation[14].

$\mu = \tan \alpha$ (7)

Where μ is the coefficient of friction and α is the angle of tilt in degree.

Result and discussion

Effect of moisture content on the seed dimensions

The basic geometric and complex geometric dimensions are shown in Table: 1-3. The length(x), width(y) and breadth(z) of the lima bean seeds increased from 15.32 ± 0.72 to 16.16 ± 0.31 mm, 7.92 ± 0.27 to 9.02 ± 0.10 mm, 4.94 ± 0.24 to 5.68 ± 0.26 mm, respectively, with increase in moisture content from 11.02 ± 0.05 to 24.15 ± 0.12 %. The relationship between length, width and geometric mean diameter and moisture content was found to be linear, as depicted in fig1-3:

$X = 0.068M_c + 14.57$ (8)

$Y = 0.082M_c + 7.008$ (9)

$Z = 0.060M_c + 4.198$ (10)

Where: M_c is moisture content in %, with values for the coefficient of determination, R^2 of 0.942, 0.988, and 0.944, respectively.

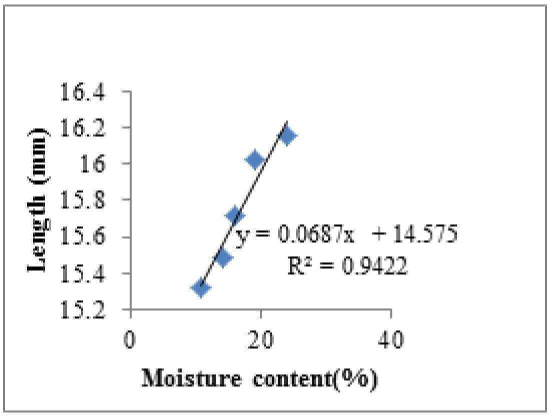

Figure 1: The effect of moisture content on length of lima bean seed.

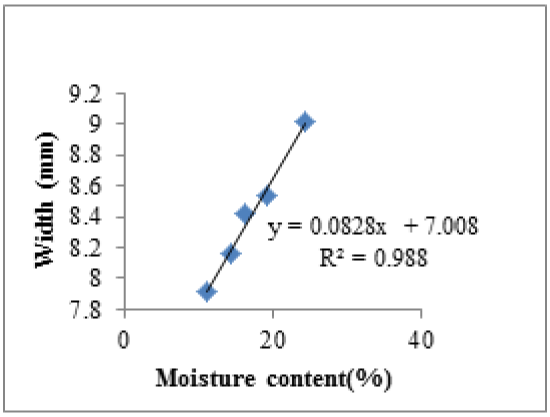

Figure 2: The effect of moisture content on width of lima bean seed.

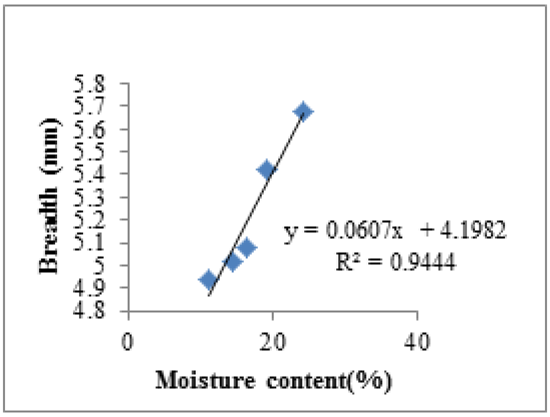

Figure 3: The effect of moisture content on breadth of lima bean seed.

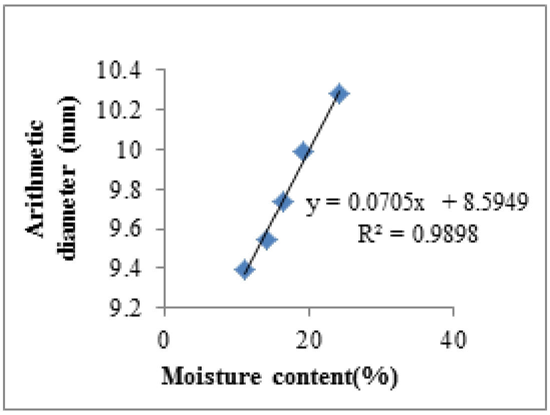

Figure 4: The effect of moisture content on Arithmetic diameter of lima bean seed.

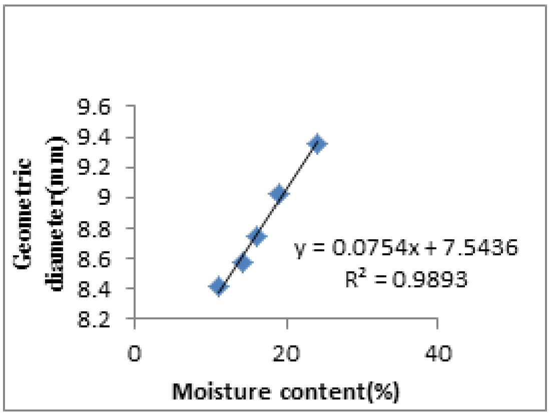

Figure 5: The effect of moisture content on geometric diameter of lima bean seed.

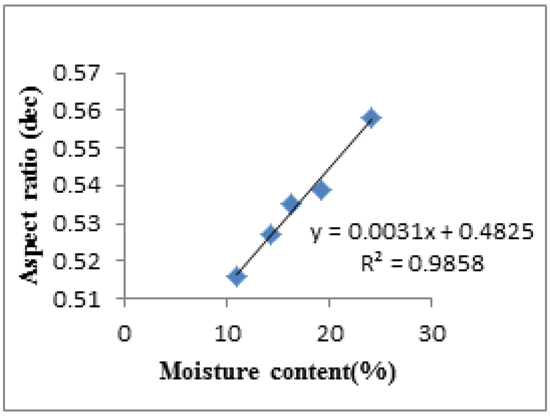

Figure 6: The effect of moisture content on aspect ratio of lima bean seed.

Where: M_c is moisture content in %, with values for the coefficient of determination, R^2 of 0.989, 0.989 and 0.985, respectively.

Seed dimension of some other grains were found to have the same properties, such as kidney bean[23], moth gram[24], green gram[25]. The dimensions values of a single lima bean were higher than those for lentils, sweet corn and pea, respectively[23, 26, 27]. The geometric mean diameter of lima bean seed is higher than coriander seeds[28], hemp seed[29].The relationship were shown in fig 9-10.

$$SMD = -0.186\,M_c + 16.11 \quad (14)$$

$$EMD = -0.197\,M_c + 16.25 \quad (15)$$

Where: M_c is moisture content in %, with values for the coefficient of determination, R^2 of 0.954 and 0.947 respectively

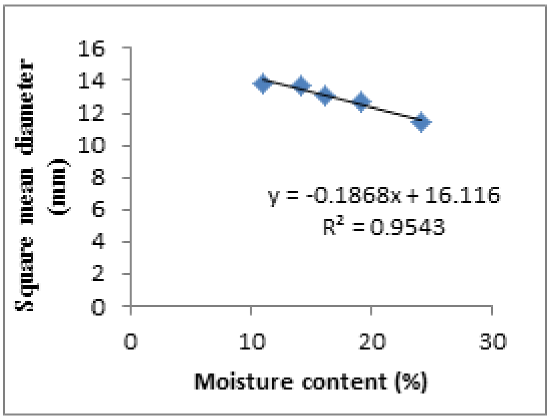

Figure 7: The effect of moisture content on square mean diameter of lima bean seed.

One thousand grain mass

The length thousand grains mass M_{1000} increased linearly from 423± 0.24 to 532 ± 0.32 g, with increase in moisture content from 11.02± 0.05 to 24.15± 0.12 %.

The relationship between One thousand grain mass and moisture content was found to be linear:

$$M_{1000} = 8.540\,M_c + 326.3 \; (R^2 = 0.994) \quad (16)$$

The lima bean has a relatively big grain size, compared with other commonly grown legume crops; for example at moisture content of 11.04%

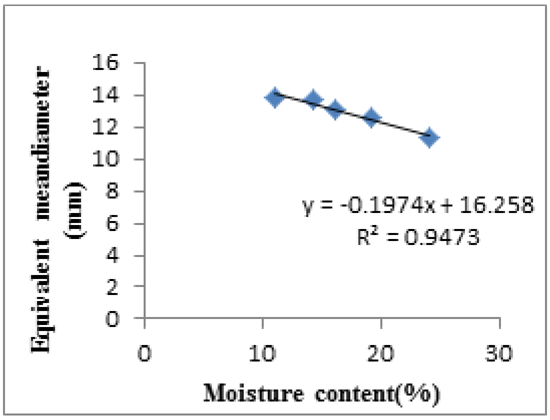

Figure 8: The effect of moisture content on equivalent mean diameter of lima bean seed.

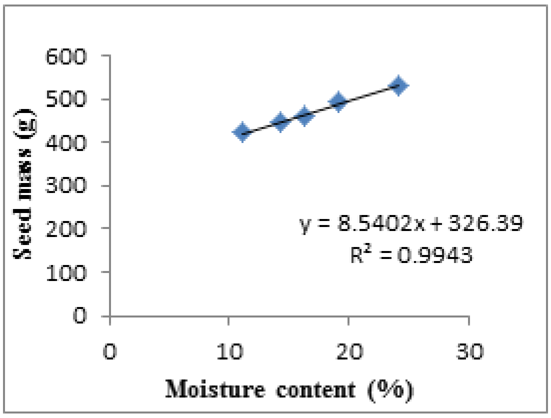

Figure 9: The effect of moisture content on one thousand grain mass of lima bean seed.

(d.b), the thousand grain mass for lima bean was 423 g while it was 245.4 g for black-eyed pea[30], 111.0 g for soybean[31] and 28.2 g for green gram [26]while it has small grain size, compared with Turkish Göynükbombay beans; about 1700 g[32].

Effect of moisture content on bulk density

The bulk density of the lima bean seeds at different moisture content decreased linearly from 0.662 ± 0.03 to 0.583 ± 0.13 gcm^{-3} within the moisture content range of 11.02 ± 0.05 to 24.15± 0.12 % (d.b). The relationship between bulk density (ρ_b) and moisture content (M_c) can be expressed as:

ρ_b= - 0.006 M_c + 0.718 (R^2=0.924) (17)

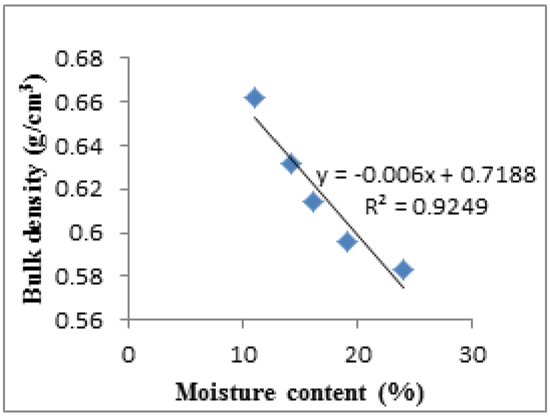

Figure 10: The effect of moisture content on bulk density of lima bean seed.

Similar trends have been reported for black-eyed pea[33], Turkish Göynükbombay beans[34] and green gram[26].

Effect of moisture content on true density

The true density of seeds increases from 0.918 ± 0.03 to 1.153 ± 0.13 gcm^{-3} within the seed moisture content range of 11.02 ± 0.05 to 24.15 ± 0.12 % (d. b.). The relationship of true density (ρ_t) and moisture content (M_c) can be expressed as (fig -11):

ρ_t = 0.019 M_c +0.679 (R^2=0.946) (18)

The decrease in bulk density of lima bean seed with increase in moisture content indicates the increase in volumetric expansion in the seed is greater than weight. Some other grains have the same trend, such as vetch seed35 and cowpea seed36.

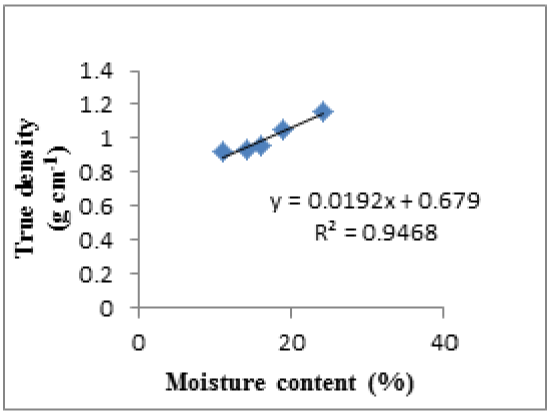

Figure 11: The effect of moisture content on true density of lima bean seed.

Effect of moisture content on porosity

The porosity of seeds was found to increase from 27.88±0.05 to 49.43±1.12 % within moisture content range of 11.02 ± 0.05 to 24.15 ± 0.12 % (d. b.). The linear relationship between the porosity (ε) and moisture content (Mc) can be expressed as in fig-12:

ε =1.714 M_c +8.779 (R^2=0.983) (19)

The porosity of lima bean with that of other grains have been found with close porosity values to[24] for kidney bean, [20]for sunflower seed, [37]for white lupine, [26]for green gram,[38]for chickpea, [32]for black-eyed pea,[39]for Balanitesaegyptiaca nuts, respectively.

The surface area of the lima bean seed was using Eq.3.The surface area of the seed increased from 222.19 ± 0.11 to 275.23 ± 0.25mm^{-2} when the moisture content increased from 11.02 ± 0.05 to 24.15 ± 0.12% (d.b).

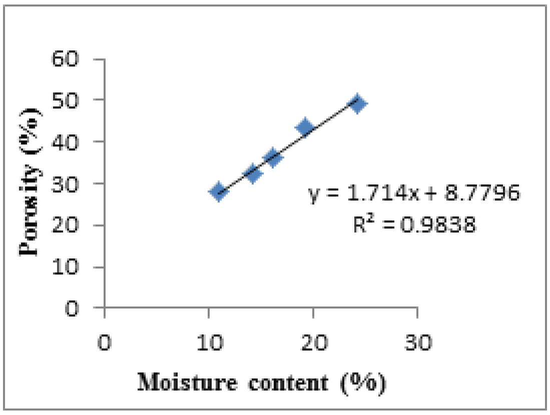

Figure 12: The effect of moisture content on porosity of lima bean seed.

Effect of moisture content on surface area

The relationship between surface area (mm2) and moisture content (Mc) can be expressed as in fig-13:

SA = 4.209 Mc +73.3 (R2=0.989) (20)

Effect of moisture content on sphericity

The sphericity was found to increase from 0.548 ± 0.01 at the moisture content of 11.02 ± 0.05 % (d.b) to a maximum value of 0.579 ± 0.09 at the moisture content of 24.15± 0.12 % (d.b). The effect of moisture content on the seed sphericity is presented in fig-14. The relationship can be expressed using the equation with a coefficient of determination as follows:

φ =0.002 Mc +0.519 (R2=0.960) (21)

The sphericity of lima bean was compared with those of other grains and it was observed that the sphericity of grain at a given moisture level was lower than those of black-eyed pea[32], Türkish Göynükbombay bean[34] and green gram[20].

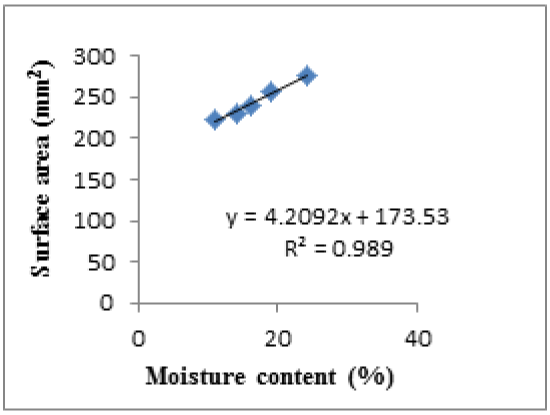

Figure 13: The effect of moisture content on surface area of lima bean seed.

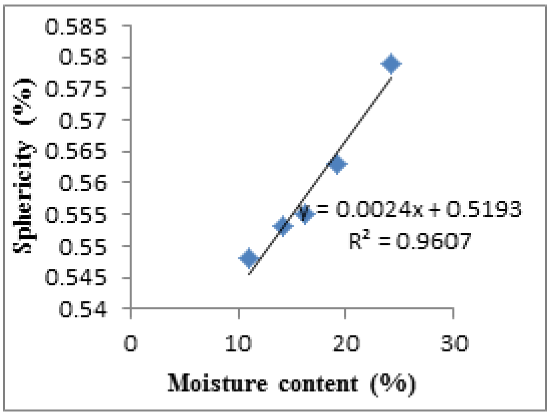

Figure 14: The effect of moisture content on sphericity of lima bean seed.

Effects of moisture content on the static coefficients of friction

The effects of moisture content and surface nature of materials on the static coefficients of friction of lima bean are shown in table-4 and depicted in fig-15-20. The static coefficient of friction on the rubber surface varied from 0.452 to 0.543, on the stainless steel from 0.321 to 0.422, on the aluminium from 0.345 to 0.499, on the plywood 0.340 to 0.403, on the galvanized iron from 0.316 to 0.403, and on the glass from 0.252 to 0.337for moisture contents between 11.02 ± 0.05 and 24.5±0.12% (d.b), respectively.

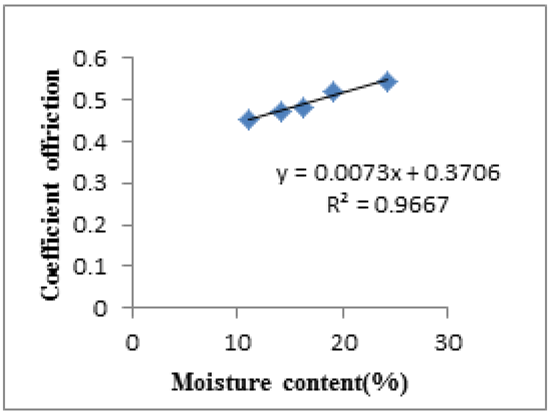

Figure 15: The effect of moisture content on coefficient of friction of lima bean seed against rubber surface.

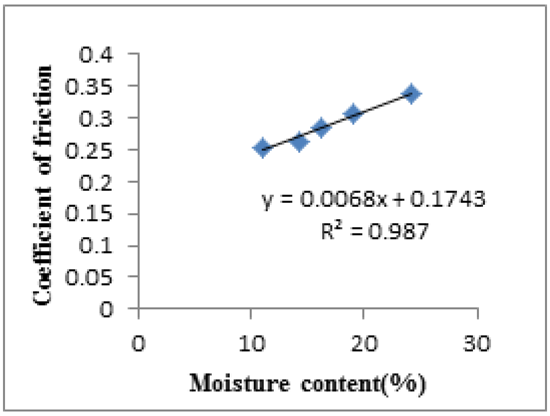

Figure 16: The effect of moisture content on coefficient of friction of lima bean seed against stainless steel surface.

The maximum static coefficients of friction were noticed on rubber surface, followed by stainless steel, plywood, galvanised iron, aluminium and glass surfaces. All the static coefficients of friction increased linearly in the moisture range of 11.02 ± 0.05 and 24.5 ± 0.12% (d.b). A similar trend was reported for unshelled peanuts[39], black-eyed pea[32], Turkish Göynükbombay beans[34], cumin seed[12] and lentil seeds[41].

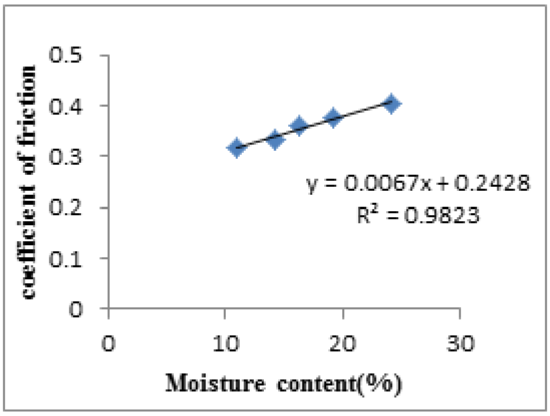

Figure 17: The effect of moisture content on coefficient of friction of lima bean seed against plywood surface.

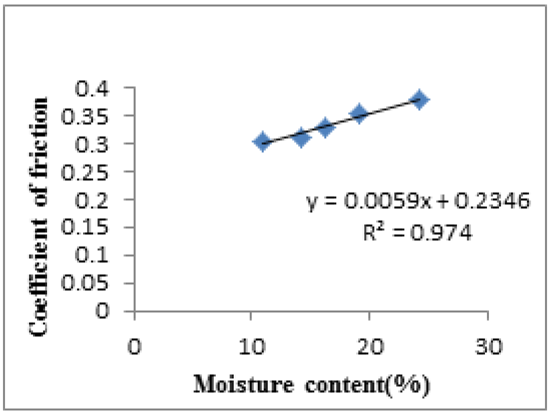

Figure 18: The effect of moisture content on coefficient of friction of lima bean seed against plywood surface.

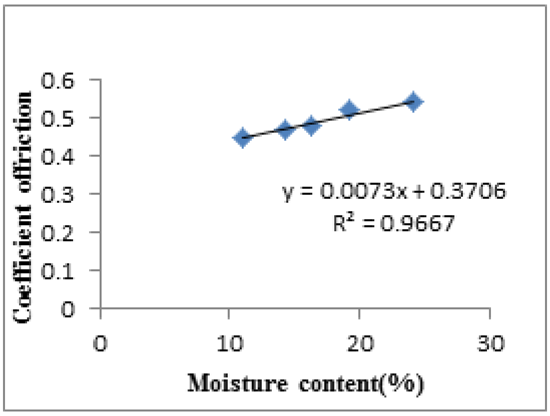

Figure 19: The effect of moisture content on coefficient of friction of lima bean seed against Galvanized iron surface.

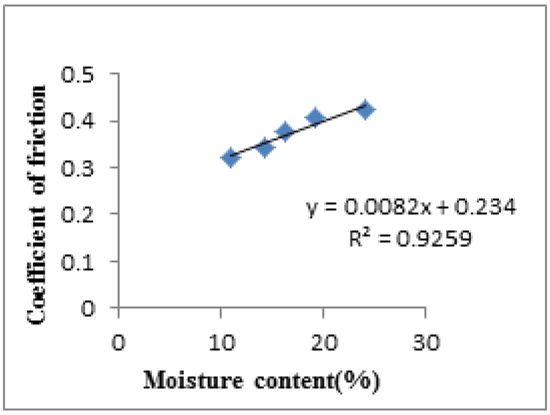

Figure 20: The effect of moisture content on coefficient of friction of lima bean seed against glass surface.

CONCLUSION

Having carried out investigations on the effect of moisture content on physical and mechanical properties of lima bean seed, it was discovered that all the linear dimensions, mass, volume, porosity , sphericity, true density, bulk density increased with increase in moisture content in the range of moisture content investigated. Length, width, thickness and geometric mean diameter of lima bean seed increases within the increase of moisture content. One thousand seed weight increases linearly within the increase of moisture content. The maximum static coefficients of friction were noticed on rubber surface, followed by stainless steel, plywood, galvanized iron, aluminium and glass surfaces. The findings from the research shows good agreement with some of the general trend and ranges obtained for other similar crops. It is of opinion that data from this test will be useful in the design and development of the appropriate machines for handling and processing of the seed.

Table 1: Basic geometric traits of lima bean germplasm

Moisture Content (%)	Axial dimension (mm)		
	Length *x* (mm)	**Width y (mm)**	**Breadth z (mm)**
11.02	15.32 ± 0.72	7.92 ± 0.27	4.94 ± 0.24
14.24	15.48 ± 0.19	8.16 ± 0.32	5.02 ± 0.20
16.23	15.72 ± 0.02	8.42 ± 0.14	5.08 ± 0.47
19.14	16.02 ± 0.21	8.54 ± 0.53	5.42 ± 0.61
24.15	16.16 ± 0.31	9.02 ± 0.10	5.68 ± 0.26

All the values of ±SD

Table 2: Basic geometric traits of Lima bean germplasm

Average diameter (mm)				
Arithmetic diameter D_a (mm)	**Geometric diameter D_g (mm)**	**Aspect ratio A_r (dec)**	**Square mean diameter (mm)**	**Equivalent diameter (mm)**
9.39 ± 0.11	8.41 ± 0.10	0.516 ± 0.01	13.81 ± 0.12	13.80 ± 0.01
9.55 ± 1.06	8.57 ± 1.26	0.527 ± 0.22	13.73 ± 1.06	13.72 ± 1.26
9.74 ± 0.10	8.74 ± 0.12	0.535 ± 0.06	13.08 ± 0.11	13.07 ± 0.10
9.99 ± 0.26	9.03 ± 0.23	0.539 ± 0.01	12.65 ± 0.06	12.65 ± 0.20
10.28 ± 0.12	9.36 ± 0.14	0.558 ± 0.05	11.47 ± 0.10	11.31 ± 0.13

All the values of ±SD

Table 3: Basic geometric traits of Lima bean germplasm

Sphericity, φ (%)	**Bulk density, ρ_b (g/cm³)**	**True density, ρ_t (g/cm³)**	**Porosity, ε (%)**	**Surface area, S (mm²)**
0.548 ± 0.02	0.662 ± 0.01	0.918 ± 0.13	27.88 ± 0.05	222.19 ± 0.11
0.553 ± 0.01	0.632 ± 0.11	0.934 ± 0.10	32.33 ± 1.00	230.73 ± 0.06
0.555 ± 0.16	0.614 ± 0.10	0.962 ± 0.14	36.17 ± 0.09	240.18 ± 0.10
0.563 ± 0.06	0.596 ± 0.02	1.053 ± 0.12	43.40 ± 1.12	256.16 ± 0.25
0.579 ± 0.10	0.583 ± 0.30	1.153 ± 0.14	49.43 ± 0.20	275.23 ± 0.15

All the values of ±SD

Table 4: Effect of moisture content on static coefficient of friction

Moisture content (%)	**Rubber**	**plywood**	**Stainless steel**	**Aluminium**	**Galvanized iron**	**glass**
11.02	0.452	0.340	0.321	0.305	0.316	0.252
14.24	0.473	0.348	0.342	0.312	0.334	0.264
16.23	0.482	0.362	0.375	0.329	0.359	0.285
19.14	0.521	0.386	0.408	0.352	0.374	0.306
24.15	0.543	0.403	0.422	0.378	0.403	0.337

Table 5: The regression coefficients and coefficients of determination for static coefficient of friction on various surfaces

Surface	Regression coefficient		Coefficient of determination (R^2)
	C_2	C_1	
Rubber	0.0073	0.370	0.9667
Stainless steel	0.0082	0.234	0.9259
Plywood	0.0052	0.280	0.9648
Galvanized iron	0.0067	0.242	0.9823
Aluminium	0.0059	0.234	0.9740
Glass	0.0068	0.174	0.9870

ACKNOWLEDGEMENTS

I avail this privilege to express my deep sense of gratitude and immense respect to Dr. C. Muthamizhchelvan, Director (E&T) for providing Lab facility and other requirements. My special and heartfelt thanks are to Ms.Uma Sundharam, for their invaluable guidance, constant moral support and valuable support.

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